

UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: August 2014

Module Number: EE5314

Module Name: Power Electronics

[Three Hours]

[Answer all questions, each question carries 10 marks]

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- Q1 a) i) Name three applications where uncontrolled and controlled rectifiers are used.
- ii) What is the advantage of using a thyristor bridge over a diode bridge?
- iii) A student needs to design a power supply of 30 V DC output using the knowledge on AC-DC converters and DC-DC converters. The following devices are available for him in the laboratory.
- I 50 V fixed AC voltage supply
 - II Diodes 5 Nos
 - III Capacitors 2 Nos
 - IV An Inductor
 - V Accessories to connect the devices (wires)
- Draw a complete circuit to implement the power supply using these devices. (Device ratings are not required and assume the devices have capable ratings for required conversions)
- [3 Marks]
- b) A fully controlled rectifier shown in Figure Q1 has an input voltage of 230 V supplying DC power to a 52.9Ω resistive and inductive load. The Converter delivers 800 W DC output to load.
- i) Plot the supply voltage $V_s(t)$ and output voltage $V_d(t)$ in the same time scale and mark the peak values.
 - ii) Derive an expression for the average output voltage using rms supply voltage V_s and firing angle α .
 - iii) Calculate the Average output voltage.
 - iv) Calculate the firing angle α .
 - v) Calculate the DC output current and the fundamental amplitude of the supply current.
 - vi) In a practical demonstration, it has been observed that the peak value of output voltage $V_d(t)$ is slightly less than the theoretical peak value calculated in part i) . What would be the reason for this discrepancy?

[7 Marks]

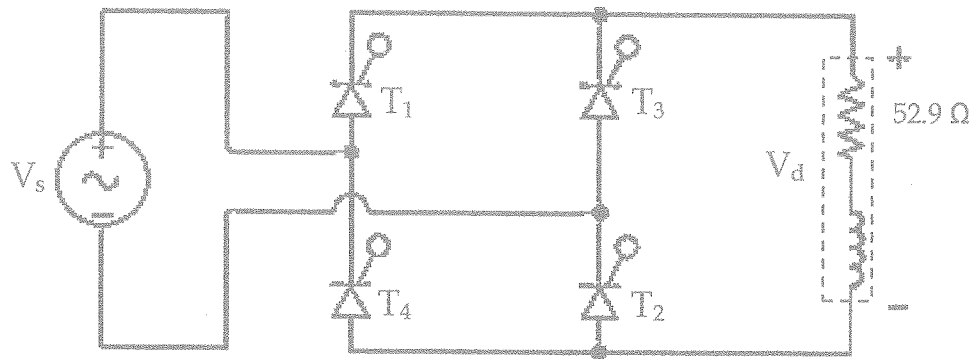


Figure Q1: Fully controlled rectifier

- Q2 a) The buck converter shown in Figure Q2 is used to regulate a DC power supply.
- i) Plot the variation of voltage across inductor v_L with time t .
 - ii) Plot the variation of inductor current i_L with time t for the general continuous conduction mode.
- [2 Marks]
- b) A buck converter is used to produce an output voltage of 18 V across a 10 Ω load resistor. The output voltage ripple must not exceed 0.5 percent. The DC supply is 48 V and the switching frequency f is 40 kHz. Assume the current across the inductor is continuous.
- i) Obtain a relationship among input voltage V_d , output voltage V_o and duty ratio D . [You may use the plots in part a) i)]
 - ii) Calculate D for this converter.
 - iii) Obtain general expressions for minimum $i_{L,min}$ and maximum $i_{L,max}$ continuous inductor current in terms of L , V_o , R , D and f . [You may use the plots in part a) ii)]
 - iv) What is the value of $i_{L,min}$ when the inductor current is at the boundary of the continuous conduction mode? Derive an expression for L using R , D and f in this situation.
 - v) Find the minimum value of inductor L_{min} required for this circuit.
 - vi) Obtain an expression for output voltage ripple $\Delta V_o/V_o$ using the capacitance C , L , f and D .
 - vii) Calculate the capacitance required for this circuit using the expression in part b) vi).

[8 Marks]

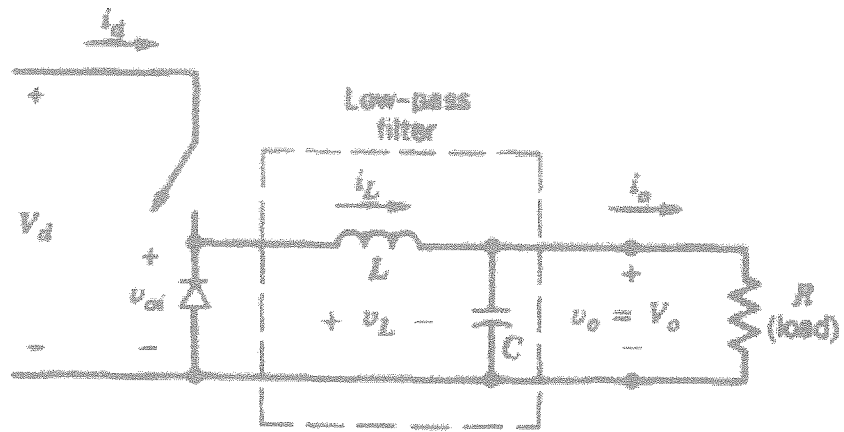


Figure Q2: Buck Converter

- Q3 a) i) Name two applications where DC to AC inverters are used.
 ii) What is the difference between Voltage Source Inverters (VSI) and Current Source Inverters (CSI)?
- [3 Marks]
- b) A general analysis of the switch-mode inverter shown in Figure Q3 is to be done. The switching frequency f_s , which is also the frequency of the triangular signal is 1450 Hz. The DC voltage V_d is 600 V. Output voltage is a sinusoidal voltage with a frequency f_1 of 50 Hz. The load is connected between the inverter leg A and the dc voltage midpoint O. Table Q3 gives the harmonics of the switch-mode inverter.

Table Q3: Harmonics of Switch-mode Inverter

h \ m_a	0.2	0.4	0.6	0.8	1.0
l	0.2	0.4	0.6	0.8	1.0
<i>Fundamental</i>					
m_f	1.242	1.15	1.006	0.818	0.601
$m_f \pm 2$	0.016	0.061	0.131	0.220	0.318
$m_f \pm 4$					0.018
$2m_f \pm 1$	0.190	0.326	0.370	0.314	0.181
$2m_f \pm 3$		0.024	0.071	0.139	0.212
$2m_f \pm 5$				0.013	0.033
$3m_f$	0.335	0.123	0.083	0.171	0.113
$3m_f \pm 2$	0.044	0.139	0.203	0.176	0.062
$3m_f \pm 4$		0.012	0.047	0.104	0.157
$3m_f \pm 6$				0.016	0.044
$4m_f \pm 1$	0.163	0.157	0.008	0.105	0.068
$4m_f \pm 3$	0.012	0.070	0.132	0.115	0.009
$4m_f \pm 5$			0.034	0.084	0.119
$4m_f \pm 7$				0.017	0.050

Note: $(\hat{V}_{Ao})_{h/2} V_d$ is tabulated as a function of m_a .

- i) Find the frequency modulation ratio, m_f . Why is it chosen as an odd number?
- ii) Calculate the output voltage (rms value of fundamental), when the amplitude modulation ratio (m_a) is equal to 0.8.

- iii) If $(V_{AO})_1 = \frac{\hat{V}_{control}}{\hat{V}_{tri}} \sin \omega_1 t \frac{V_d}{2}$, prove that $(V_{AO})_1 = m_a \frac{V_d}{2}$.
- iv) Compute the rms value of the 5 most dominant harmonics of V_{AO} (at $m_a = 0.8$), by using Table Q3, and indicate the frequencies at which these harmonics appear.
- v) What changes need to be done to generate a square pulse using the above inverter?

[7 Marks]

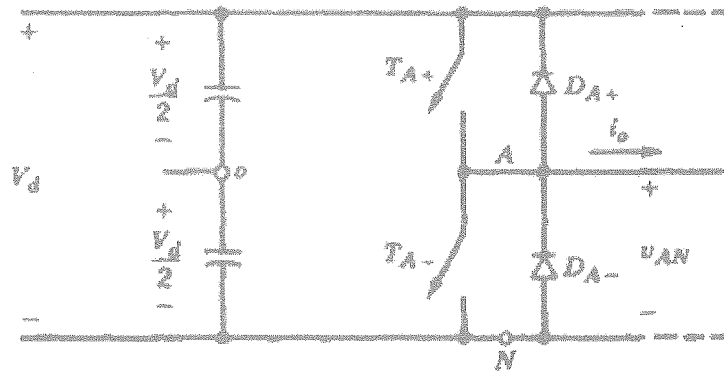


Figure Q3: Switch-mode Inverter

- Q4 a) i) Name two types of control methods used in AC voltage controllers.
- ii) Describe the difference between these two types of control methods.
- iii) A Single-phase controlled AC voltage controller with an inductive (RL) load is shown in Figure Q4a. Plot the supply voltage V_s , output current i_o and output voltage V_o in the same time scale. Assume $\alpha = 30^\circ$.

[3 Marks]

- b) An AC voltage controller is shown in Figure Q4b. It is connected to a resistive load R of 10Ω . Input voltage V_s is 120 V , 60 Hz . The thyristors are switched ON for 25 cycles and switched OFF for 75 cycles.
- i) Identify the control method of this circuit.
- ii) If the number of switched ON cycles are n and switched OFF cycles are m , derive an expression for rms output voltage $V_{o,rms}$.
- iii) Calculate $V_{o,rms}$.
- iv) Calculate the input power factor.
- v) Calculate the thyristor rms current.
- vi) Normally there is a reduction of switching harmonics in this control method. What would be the reason for such a reduction?

[7 Marks]

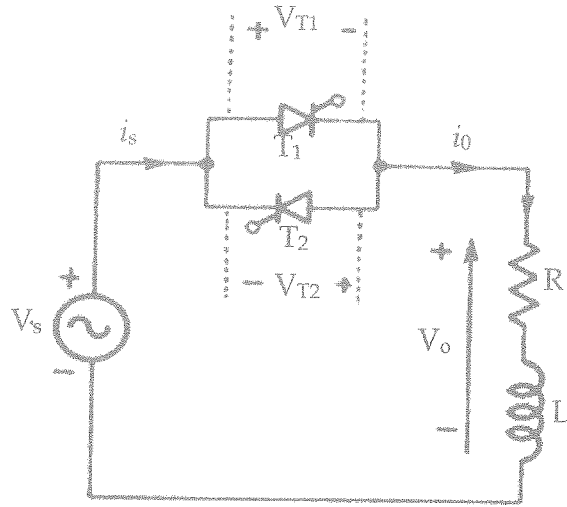


Figure Q4a: Single-phase controlled AC voltage controller

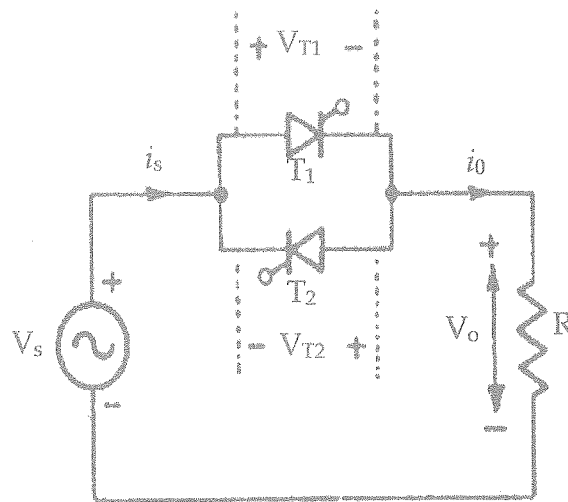


Figure Q4b: AC voltage controller

- Q5 a) i) What are the operating quadrants of a full bridge converter? Show them in the I_o - V_o plane.
- ii) The bridge may be controlled by using Bipolar or Unipolar PWM (Pulse Width Modulation). Describe the advantages and disadvantages of these techniques.
- [2 Marks]
- b) A full bridge converter is shown in Figure Q5. $V_d = 30$ V. Switching frequency is 30 kHz. The bridge is controlled to provide an average output voltage $V_o = 200$ V. Bipolar PWM technique is used.
- i) What is the ripple frequency output of the circuit?
- ii) Show how this Bipolar PWM technique is achieved using a triangular waveform (V_{tri}) and a Control Voltage ($V_{control}$) by plotting V_{tri} and $V_{control}$ with time t .
- iii) Plot the Output Voltage V_o with time t mentioning peak voltages, periodic time T_s and switch ON time T_{ON} . [You may use the same time scale as part b) ii)]

- iv) Derive expressions for duty ratios D_1 and D_2 and calculate D_1 and D_2 .
- v) If Unipolar PWM is used, what is the ripple frequency of the output?

[8 Marks]

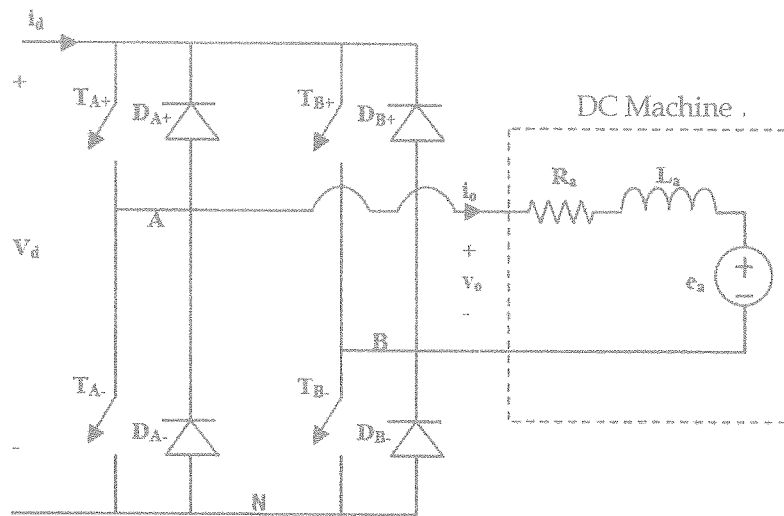


Figure Q5: Full bridge converter